Planting Date and Preplant Weed Management Influence Yield, Water Use, and Weed Seed Production in Herbicide-Free Forage Barley

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In the semiarid northern Great Plains, the adoption of zero tillage improves soil water conservation, allowing for increased crop intensification and diversification. Zero-tillage crop production relies heavily on herbicides for weed management, particularly the herbicide glyphosate, increasing selection pressure for herbicide-resistant weeds. Barley is well adapted to the northern Great Plains, and may be a suitable herbicide-free forage crop in zero-tillage systems. A 2-yr field study was conducted to determine if planting date influenced crop and weed biomass, water use (WU), and water-use efficiency (WUE) of barley and weed seed production in three preplant weed management systems: (1) conventional preplant tillage with a field cultivator (TILL); (2) zero tillage with preemergence glyphosate application (ZTPRE); and (3) zero tillage without preemergence glyphosate (ZT). None of the systems included an in-crop herbicide. Planting dates were mid-April (early), late May (mid), and mid-June (delayed). Early planting of ZT barley resulted in excellent forage yields (7,228 kg/ha), similar to those from TILL and ZTPRE. Early planting resulted in a small accumulation of weed biomass, averaging 76 kg/ha, and no weed seed production regardless of preplant weed management system. Early planting resulted in higher WU than delayed planting, averaging 289 and 221 mm, respectively, across management systems and years. The WUE of crop and total biomass did not differ among preplant weed management systems at harvest from the early planting date. Delayed planting resulted in decreased forage yield with high amounts of weed biomass and seed production, especially in ZT. A pre-emergence glyphosate application was not necessary for early-planted ZT forage barley. Early planting of herbicide-free barley for forage can be an excellent addition to northern Great Plains cropping systems as part of a multitactic approach for improved weed and water management.
Nomenclature: Glyphosate; barley, *Hordeum vulgare* L.
Key words: Integrated weed management, integrated crop management, zero tillage, weed density, water-use efficiency.

Reduction of herbicide use with a concomitant improvement in weed management would improve environmental and economic sustainability of dryland cropping systems in semiarid regions (Derksen et al. 2002). World wide, weeds are potentially responsible for an estimated crop loss of 34% (Oerke 2006). Water typically is the most limiting factor for crop production in semiarid regions (Lenssen et al. 2007; O'Leary and Connor 1997), but in some areas, including Montana and North Dakota, herbicide costs can be the highest single input cost for producers.

The adoption of zero tillage has led to improved soil water management and increased water use by subsequent crops, allowing for greater cropping diversification and intensity (Hatfield et al. 2001). Zero-tillage crop production relies primarily on herbicides, particularly glyphosate, for weed management (Shaner 2000). Populations of 13 previously susceptible cropland weed species now exhibit resistance to glyphosate, including horseweed [*Conyza canadensis* (L.) Cronq.] (Heap 2008; Koger et al. 2005). Other important cropland weeds, including green foxtail [*Setaria viridis* (L.) Beauv.] and wild oat (*Avena fatua* L.), have populations resistant to other commonly used herbicides (Heap 1997), but resistance to glyphosate has not been reported for these species. Decreasing selection pressure for resistance is recommended to maintain herbicide efficacy within weed populations. One practice to reduce selection pressure is to rotate herbicidal modes of action (Mallory-Smith and Retzinger 2003); another recommended practice is to produce crops that simply require little or no herbicide inputs (Nazarko et al. 2003).

The inclusion of forages in crop rotations is a long-term practice in the northern Great Plains (Newell 1948). Annual forage crops, particularly barley, are well adapted to semiarid regions, producing good yields with nutritive values suitable for overwintering beef cattle (*Bos taurus* L.) in the northern Great Plains (Carr et al. 2004; McCartney et al. 2004). In the Canadian prairie, Entz et al. (1995) reported that 83% of surveyed producers thought that annual crops following forages had fewer weed problems than when crops followed annual grain crops. Nazarko et al. (2005) presented evidence that inclusion of forages into grain systems was effective in reducing weed seed banks compared to annual cereal grain cropping systems without forages.

The development of multitactic approaches for weed management is necessary, particularly for zero-tillage systems (Anderson 2005; Anderson et al. 1999). Annual barley forage may be a superior choice as a herbicide-free crop in dryland systems because of its potential for high yield, good water-use efficiency (WUE), and competitiveness with weeds. A field trial was conducted to determine if planting date influenced forage and weed biomass, water use (WU), WUE of forage barley, and weed seed production in diverse weed management systems.

Materials and Methods

Experimental Site. The experimental site was located in an area mapped as Dooley sandy loam (fine–loamy, mixed, superactive, frigid Typic Argiustolls; pH 5.7, 1.7% organic

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Table 1. Monthly mean temperature and precipitation at Froid, MT during the growing season, 2004–2005.

Month	Mean temperature		Precipitation		
	2004	2005	2004	2005	Long term
	C		mm		
April	6	8	18	6	30
May	10	10	73	96	52
June	14	17	33	170	75
July	19	21	85	38	52
August	16	19	62	46	40
September	14	14	22	2	36
Total	–	–	332	423	340

matter) soil 11 km south of Froid, MT. Soils of the Dooley series are deep and well drained, with 50 to 100 cm of alluvium or eolian parent material overlaying glacial till or lacustrine deposits. Slopes of Dooley series range from 0 to 15%, but plots were located on areas with 2 to 3% slopes. Mean annual precipitation at the site is 340 mm, with about 80% occurring from April through September (Table 1). The experimental area was planted to spring cereals in rotation with summer fallow for 10 yr prior to this experiment, except for 2000, when corn (*Zea mays* L.) and flax (*Linum usitatissimum* L.) were planted in single, uniformly managed blocks. The experimental area followed barley each year.

Study Design. The experimental design was a randomized complete block in a split-plot arrangement. Whole-plot treatment was planting date, with three dates of planting each year. Subplots were three weed management systems: (1) conventional, preplant tillage (TILL); (2) zero-tillage planting with a pre-emergence glyphosate application (ZTPRE); and (3) zero-tillage planting without a pre-emergence glyphosate application (ZT). Individual subplot size was 3.1 m by 9.1 m. There were four replicates of each subplot treatment within each of the three planting dates in 2004 and 2005. Planting dates were April 20, 2004 and 2005 (early), June 1, 2004 and May 23, 2005 (mid), and June 15, 2004 and 2005 (delayed).

Crop and Weed Management. Preplant conventional tillage was done with a field cultivator equipped with 45-cm-wide sweeps and coil-tooth spring harrows with 60-cm bars. Tillage depth was 7 to 8 cm, which was controlled by stabilizer wheels on the field cultivator frame. The ZTPRE plots were treated with glyphosate at 0.2 kg ai applied in 38 L/ha water with a tractor-mounted spray boom within 24 h after planting. The ZT (without PRE glyphosate) was planted directly into resident weeds.

'Haybet' barley was fertilized and planted at 78 kg seed/ha with a 3-m-wide drill with row spacing of 20 cm. The drill was equipped with double-shoot Barton[1] openers for low-disturbance single-pass seeding and fertilization. Annual applications of nitrogen (46–0–0), phosphorus (11–52–0), and potassium (0–0–60) fertilizers were conducted for all barley plots at 170, 56, and 48 kg/ha, respectively, as per Montana State University recommendations (Jacobsen et al. 2003). Fertilizers were placed in a single band about 5 cm below and to the side of the seed row. Immediately following planting, plot areas were land rolled to push rocks back into the soil. Land rolling is a common practice for cereal hay, pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), and alfalfa (*Medicago sativa* L.) crops in many glaciated regions of the northern Great Plains, primarily to prevent rocks from damaging forage and combine harvesters.

Harvest of crop and weeds was done when barley development was late milk to early dough stage, 7.5 to 8.3 on Zadoks scale (Zadoks et al. 1974), by hand clipping two 0.5-m^2 quadrats per plot. Barley was separated from weeds. Weeds were identified, counted by species, reproductive structures quantified by species, and weed biomass then composted by harvested quadrat into a paper bag. Bagged weed and crop samples were transported to a laboratory and placed into a forced-air oven at 55 C until dry, and weighed. Harvest dates for early, mid, and delayed planting were July 9, July 27, and August 11 in 2004 and July 5, July 22, and August 12 in 2005.

Weed seed enumeration method varied by species and quantity of production. For the predominant grass weeds, wild oat and green foxtail, panicle number was determined in each 0.5-m^2 harvested area. In most plots, 10 representative panicles were taken from just outside the hand-harvested areas for determination of seed production. Samples were hand threshed on a rubberized board, and then cleaned with combinations of sieves and a seed blower[2] prior to counting. Small or shriveled seed were removed prior to counting. Seed production was calculated as number of panicles/m^2 multiplied by the number of seed/panicle. For redroot pigweed (*Amaranthus retroflexus* L.) and ribseed sandmat (*Chamaesyce glyptosperma* Engelm.), 5 or 10 representative plants were harvested from outside the hand-harvested area of each plot. Sample processing was done as previously described for grass weeds. Seed production was calculated as number of seed/plant multiplied by the number of plants/m^2. Flixweed [*Descurainia sophia* (L.) Webb ex Prantl] seed production was determined by counting the number of siliques on each plant present. Ten siliques per plot were placed in a paper bag and taken to a laboratory; following cleaning and counting, seed production was calculated as number of siliques/m^2 by number of seed/silique. Seed production from the single catchweed bedstraw (*Galium aparine* L.) and two wild buckwheat (*Polygonum convolvulus* L.) plants that produced seed was determined in the field at harvest.

Samples for soil water determinations (mass balance) were collected by hydraulic probe preplant and postharvest to 1.05-m depth in five increments, 0 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 105 cm. Plant WU was calculated as preplant soil water + rainfall - postharvest soil water. The crop WUE was calculated as barley yield divided by WU. The total forage WUE was calculated as the sum of barley biomass and weed biomass divided by WU. Surface water runoff was not significant during the course of the study, and it was assumed that neither overland flow nor leaching of water below the sampled 1.05-m soil profile occurred during the growing seasons.

Statistical Analyses. Data were analyzed with SAS (SAS 2003) with the use of the PROC MIXED procedure with appropriate error terms for a split-plot analysis with all treatment factors and year considered fixed effects. When

Table 2. Effect of planting date and year on preplant weed density and biomass in zero-tillage management.

Planting date[a]	Weed density 2004	Weed density 2005	Weed biomass 2004	Weed biomass 2005
	plants/m²		g/m²	
Early	4 b[b]	9 c	< 0.1 c	0.3 c
Mid	494 a	97 b	3.2 b	11.6 b
Delayed	413 a	223 a	6.4 a	72.9 a

[a] Early planting date 1, April 20, 2004 and 2005; mid planting date 2, June 1, 2004, May 23, 2005; delayed planting date 3, June 15, 2004 and 2005.

[b] Means within years and parameter followed by the same letter are not significantly different based on Fisher's Protected LSD test (0.05).

treatment interactions with year were significant, analyses were done within years. When variances were not homogeneous, data were transformed with the use of log(x) or log(x + 1) prior to analyses. For weed seed production analyses, planting dates or treatments that had no seed production were not included in the analysis. Mean separation for individual treatments was done with Fisher's Protected LSD test at the 0.05 level.

Results and Discussion

Growing Season Environment. The 2004 growing season had below-average precipitation in April and June, and above-average precipitation in May, July, and August (Table 1). The 2005 growing season had below-average precipitation in April and July, and above-average precipitation in May and June. Mean temperature was higher in 2005 than 2004 for April, June, July, and August.

Weed Density and Biomass. Preplant weed density and biomass varied by planting date and year for ZT (Table 2). At the first planting date, weed density was low (< 9 weeds/m^2) and plants were small. Weed density was dramatically higher at the second and third planting dates in 2004, although weed biomass accrual was slow, perhaps because of the intense competition and cooler temperatures. In 2005, weed density and weed biomass increased with each subsequent planting date.

Across planting dates, the primary species present at planting were redroot pigweed, green foxtail, and western rockjasmine (*Androsace occidentalis* Pursh) in 2004 and green foxtail, western rockjasmine, kochia [*Kochia scoparia* (L.) Schrad] and wild oat in 2005 (Table 3). The primary species present at the first planting date for 2004 and 2005 was western rockjasmine, with Russian thistle (*Salsola iberica* Sennen & Pau) being the only other observed species. In 2004, redroot pigweed, green foxtail, and western rockjasmine represented nearly 82% of the weeds present at planting on the second and third planting dates. These three species, plus kochia, horseweed, ribseed sandmat, and Russian thistle, comprised 99% of the weeds present at the second and third planting dates. In 2005, green foxtail, western rockjasmine, kochia, wild oat, and Russian thistle comprised 92% of observed plants at the second and third planting dates.

Planting date and year influenced weed density at harvest (Figure 1). In 2004, weed density at harvest was greater in the first planting date than for the second and third planting dates. In 2005, weed density was greater at harvest from the first and third planting dates than density at harvest from the second planting date. The two experimental sites were only 200 m apart, followed the same crop the previous year, and were located in the same soil mapping unit, yet weed densities

Table 3. Effect of year on preplant weed communities in zero tillage prior to planting and at harvest across three preplant weed management systems averaged across three planting dates.

Weed species		Percent of weed community			
		Preplant ZT[a]		Harvest	
Common name	WSSA code	2004	2005	2004	2005
Barnyardgrass	ECHCG	0	0	6	< 1
Catchweed bedstraw	GALAP	0	0	0	< 1
Common cocklebur (*Xanthium strumarium* L.)	XANST	0	0	0	< 1
Common lambsquarters (*Chenopodium album* L.)	CHEAL	0	0	< 1	< 1
Common purslane (*Portulaca oleracea* L.)	POROL	0	0	< 1	< 1
Flixweed	DESSO	0	< 1	0	< 1
Green foxtail	SETVI	27	26	61	36
Horseweed	ERICA	5	2	< 1	1
Kochia	KCHSC	7	19	1	15
Prickly lettuce (*Lactuca serriola* L.)	LACSE	0	0	< 1	< 1
Redroot pigweed	AMARE	36	2	5	15
Ribseed sandmat	EPHGL	4	0	25	< 1
Russian thistle	SASKR	2	8	< 1	6
Salsify (*Tragopogon* ssp.)		0	0	< 1	< 1
Stinkgrass [*Eragrostis cilianensis* (All.) E.Mosher]	ERACN	0	0	0	< 1
Sweetclover (*Melilotus* ssp.)		0	0	< 1	5
Tumblemustard	SSYAL	0	0	< 1	< 1
Western rockjasmine		19	20	< 1	0
Wild buckwheat	POLCO	0	0	< 1	0
Wild oat	AVEFA	0	19	0	18

[a] Abbreviation: ZT, zero tillage without preemergence glyphosate application.

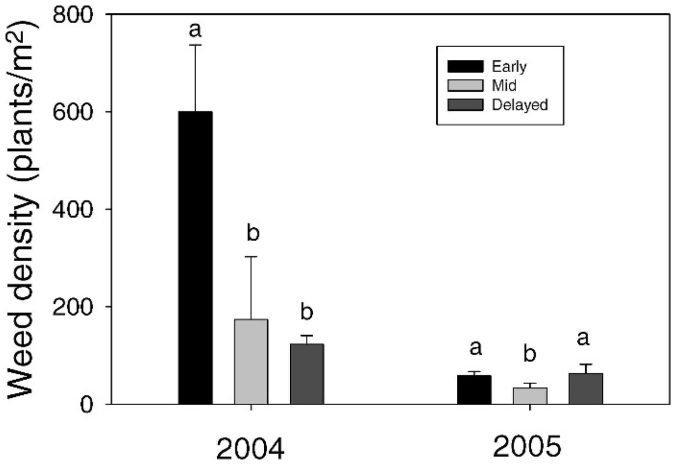

Figure 1. Effect of planting date and year on weed density at harvest. Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004 and May 23, 2005; delayed planting date, June 15, 2004 and 2005. Means within years followed by the same letter are not different based on Fisher's Protected LSD test (0.05).

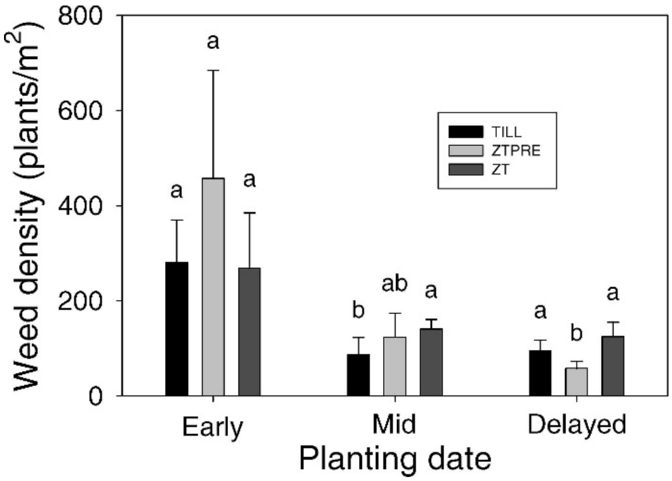

Figure 2. Effect of planting date and preplant weed management on weed density at harvest from 2004 and 2005. TILL, preplant tillage; ZTPRE, zero tillage with preemergence glyphosate; ZT, zero tillage without preemergence glyphosate. Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004 and May 23, 2005; delayed planting date, June 15, 2004 and 2005. Means within years followed by the same letter are not different based on Fisher's Protected LSD test (0.05).

were much higher for all planting dates in 2004 than in 2005. Soil moisture and temperature impact seed germination and emergence, and wide fluctuations in temperature and precipitation commonly occur during spring months in the northern Great Plains. April and May precipitation were similar for 2004 and 2005. On May 3, 2005 air temperature (1.8 m above ground level) remained below − 6 C for 7 hr with an absolute minimum of − 13 C, possibly increasing mortality of emerged seedlings. The minimum soil temperature (− 5 cm) on that date was 8 C, indicating that germinated seed at that depth would not likely have been damaged by freezing; however, temperature data from shallower soil depths are not available. Another possibility for the disparity in weed density between years could be differences in weed seed bank density between the planted blocks despite their having had similar crops and management practices over time.

Planting date and preplant weed management influenced weed density at harvest (Figure 2). The ZT and ZTPRE had similar weed densities at harvest from the first and second planting dates, suggesting that PRE glyphosate application was not necessary for early- and midseason planting dates for forage barley in zero-tillage systems. Weed density at harvest from the second planting date was higher in ZT than TILL, whereas ZTPRE had an intermediate weed density. For the third planting date, ZT had higher weed density at harvest than did ZTPRE and TILL.

Sixteen weed species were present at harvests in 2004. Green foxtail, ribseed sandmat, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], redroot pigweed, and kochia comprised 98% of the weed community across harvests in 2004, with green foxtail responsible for the largest percentage (Table 3). The weed community was comprised of 17 species at harvests in 2005, with green foxtail, wild oat, kochia, redroot pigweed, and Russian thistle comprising 90% of total individuals at harvest. In both years, western rockjasmine, a diminutive winter annual, was notably absent at harvest despite representing about 20% of the weed community at planting. Presumably, this ephemeral species was not competitive with barley or predominant weeds for light or nutrients.

Planting date, preplant weed management, and year influenced weed biomass at harvest (Table 4). For both years, weed biomass at harvest of the first planting date was low and similar among preplant weed management treatments. For the second planting date in 2004, ZT accumulated greater weed biomass than did TILL. ZT had greater weed biomass at harvest than did TILL and ZTPRE from the second planting date in 2005 and the third planting date in 2004 and 2005. The TILL and ZTPRE effectively eliminated annual weeds prior to crop emergence, whereas ZT planting without PRE glyphosate allowed for high densities of weeds to survive until harvest. The greater weed biomass in TILL compared to ZTPRE in 2005 may have been due to the presence of wild oat, a species that can respond to disturbance with increased germination rate and subsequent emergence. In a field trial at Carman, Manitoba, Schoofs and Entz (2000) compared total biomass, crop and weed combined, of spring triticale (X *Triticosecale*) and selected perennial forage entries. They reported that weed biomass of 3,726 kg/ha produced with the spring triticale was 92% of total biomass. In the present study, weeds as a percentage of total biomass averaged 37, 10, and 79% for TILL, ZTPRE, and ZT systems, respectively, for the third planting date. Conversely, across systems and years, early seeding (mid-April) resulted in weed biomass accounting for only 1% of total biomass at harvest. The weed community reported by Schoofs and Entz (2000) was predominantly green foxtail, wild buckwheat, redroot pigweed, wild mustard (*Sinapis arvensis* L.), green smartweed (*Polygonum scabrum* L.), and wild oat. Weed populations at harvest in the current study were predominantly green foxtail, wild oat, ribseed sandmat, redroot pigweed, kochia, Russian thistle, and horseweed, with 12 other species present in lesser numbers. However, early

Table 4. Effect of preplant weed management and planting date on aboveground biomass of weeds and barley, 2004–2005.

	2004			2005		
	Planting date[a]					
Biomass source/preplant weed management	Early	Mid	Delayed	Early	Mid	Delayed
Weed	kg/ha					
Tilled	48 a[b]	159 b	239 b	115 a	90 b	2,815 b
Zero tillage + glyphosate	154 a	306 ab	251 b	36 a	184 b	449 c
Zero tillage	64 a	630 a	3,083 a	41 a	1,751 a	6,267 a
Barley						
Tilled	6,753 a	5,105 a	3,292 a	7,935 b	5,305 a	1,340 b
Zero tillage + glyphosate	5,672 b	4,747 a	3,931 a	8,690 a	5,658 a	2,384 a
Zero tillage	5,729 b	4,301 a	1,732 b	8,589 ab	4,302 a	180 c

[a] Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004, May 23, 2005; delayed planting date, June 15, 2004 and 2005.

[b] Means within planting date and biomass source followed by the same letter are not different based on Fisher's Protected LSD test (0.05).

planting resulted in low weed and high crop biomass at harvest, despite the presence of a wide range of important and potentially competitive weed species.

Crop Biomass. Planting date, preplant weed management, and year influenced barley biomass at harvest (Table 4). For the first planting date in 2004, barley planted TILL had the greatest crop biomass. For the second planting date, preplant weed management treatments resulted in similar accumulation of crop biomass, averaging 4,718 kg/ha. However, for the third planting date, ZTPRE and TILL treatments produced more biomass at harvest than did ZT barley, presumably due to a high level of weed interference. In 2005, barley biomass at harvest was greater for ZTPRE than for TILL from the first planting date. Yield was similar among preplant weed management treatments for the second planting date, and averaged 5,088 kg/ha. For the third planting date, barley biomass at harvest was highest from ZTPRE, whereas yield from ZT was particularly low. In both years, barley biomass at harvest decreased with later planting date despite differences in precipitation, temperature, and weed density. Averaged over preplant weed management systems and years, yield loss resulting from delayed planting of barley was 5,085 kg/ha, nearly a 70% reduction compared to yield from the early planting date. Crop biomass yields from the first and second planting date document that barley is well adapted as a hay crop in the semiarid northern Great Plains, a finding previously reported by Carr et al. (1998, 2004). Forage barley yields in our delayed planting date (mid-June) were lower, averaging only 2,143 kg/ha across years and preplant weed management systems, presumably due to a combination of weed competition and heat stress during crop growth and development.

Water Use and Water-Use Efficiency. The effect of year by planting date influenced WU of barley and associated weeds (Figure 3). Water use in 2004 was similar between first and second planting dates, and both had greater water use than did the third planting date. Water use was higher for the first planting date than for the second and third dates in 2005.

The influence of year and interactions with year were significant for WUE of crop biomass, so results are presented by planting date and preplant weed management system for each year. In 2004, WUE of barley biomass was similar among preplant weed management systems for the first and second planting dates (Table 5), averaging 31.6 and 25.0 kg/ha/mm, respectively. For the third planting date, crop biomass WUE was greater for TILL and ZTPRE than for ZT. Crop biomass WUE was similar among preplant weed management systems for the first planting date of 2005, averaging 22.2 kg/ha/mm across treatments (Table 5). However, for the second and third planting dates in 2005, the WUE of crop biomass was greatest for ZTPRE, intermediate for TILL, and least for ZT.

The WUE of forage biomass varied for effects of preplant weed management and year. Due to the large accumulation of weed biomass, ZT had higher forage biomass WUE (26.0 kg/ha/mm) than did TILL or ZTPRE (23.5 and 22.9 kg/ha/mm, respectively). The WUE was higher in 2004 than 2005, with values of 28.9 and 19.4 kg/ha/mm, respectively. Where it is well adapted, forage barley may have superior WUE when compared with other spring-seeded cereals due to its more rapid development and earlier potential harvest.

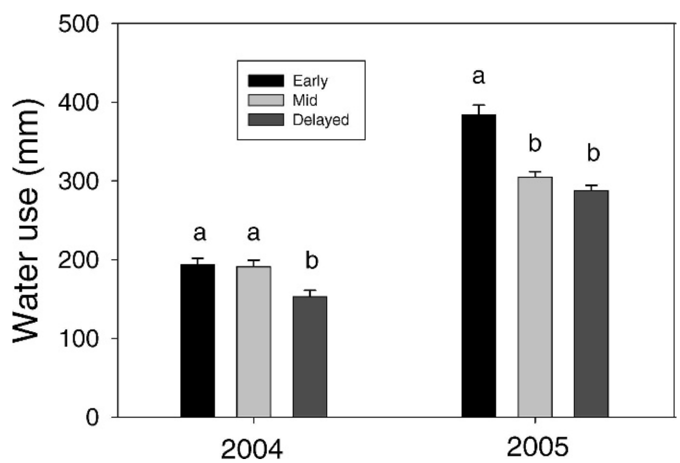

Figure 3. Effect of planting date and year on water use from barley across three preplant weed management treatments. Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004 and May 23, 2005; delayed planting date, 15 June 2004 and 2005. Means within planting dates followed by the same letter are not different based on Fisher's Protected LSD test (0.05).

Table 5. Effect of planting date and preplant weed management on water-use efficiency of barley biomass, 2004–2005.

Year/preplant weed management	Barley WUE[a] Early planting date[b]	Mid planting date	Delayed planting date
	kg/ha/mm		
2004			
Tilled	33.9 a[c]	26.0 a	24.0 a
Zero tillage + glyphosate	28.1 a	24.5 a	24.7 a
Zero tillage	32.7 a	24.5 a	11.7 b
2005			
Tilled	20.4 a	17.2 a	4.6 b
Zero tillage + glyphosate	23.4 a	19.5 a	8.6 a
Zero tillage	22.9 a	13.7 b	0.5 c

[a] Abbreviation: WUE, water-use efficiency.

[b] Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004, May 23, 2005; delayed planting date, June 15 2004 and 2005.

[c] Means with columns and years followed by the same letter are not different based on Fisher's Protected LSD test (0.05).

Table 7. Effect of planting date and preplant weed management on total weed seed production, 2005.

Preplant weed management	Planting date[a] Early	Mid	Delayed
	No./m^2		
Tillage	0	39 b[b]	11,702 a
Zero tillage + glyphosate	0	213 b	13,587 a
Zero tillage	0	11,498 a	27,507 a

[a] Early planting date, April 20, 2005; mid planting date, May 23, 2005; delayed planting date, June 15, 2005.

[b] Means within planting date followed by the same letter are not significantly different based on Fisher's Protected LSD test (0.05).

Weed Seed Production. Planting date strongly influenced weed seed production both years. Importantly, there was no weed seed production at harvest of the first planting date in either year (Tables 6 and 7) regardless of preplant weed management, strongly suggesting that early planting and forage harvest of barley can be an effective weed management practice in the Northern Great Plains. Few weeds had emerged prior to the first planting date, and despite high densities of associated weeds at forage harvest, weeds present were small and had not produced seed. Due to its rapid germination, emergence, and phenological development, barley can be an exceptionally competitive crop with weeds.

Eight weed species produced seed from second and third planting dates by the time of barley harvest: green foxtail, redroot pigweed, wild oat, flixweed, ribseed sandmat, catchweed bedstraw, wild buckwheat, and barnyardgrass. Green foxtail, wild oat, flixweed, and ribseed sandmat produced seed by harvest of the mid and delayed planting dates, and except for flixweed, all produced more seed from the later planting date (Table 6). In 2005, all seven flixweed plants present at harvest of the second planting date produced seed.

Preplant weed management influenced weed seed production, but results were not consistent among the species present in this trial (Table 6). Green foxtail and wild oat produced more seed with ZT than with ZTPRE management. Harker et al. (2003) documented that early harvest of ZTPRE barley as silage reduced wild oat densities under zero tillage in the absence of in-crop herbicides. Flixweed seed production, along with minor amounts of seed from wild buckwheat, catchweed bedstraw, and barnyardgrass, occurred only in ZT. Conversely, redroot pigweed produced seed in TILL and ZTPRE, but it did not produce seed in ZT, perhaps due to competition from the earlier emerged weeds that were not killed prior to planting or crop emergence in ZT.

Total weed seed production varied by planting date and preplant weed management in 2004, primarily due to the large influence of green foxtail, which produced 94% of all seed that year (Table 6). Later planting dates resulted in increased seed production. Weeds in ZT produced more seed than did weeds in TILL. In 2005, the interaction of planting date and preplant weed management influenced total weed seed production (Table 7). As discussed previously, early planting resulted in no weed seed production at harvest, regardless of preplant weed management. Weed seed production was greater from ZT than TILL or ZTPRE at harvest from the second planting date. Weed seed production at harvest from the third planting date did not vary among

Table 6. Effect of planting date or preplant weed management on weed seed production.[a]

Parameter	Total 2004	EPHGL 2004	SETVI 2004	SETVI 2005	AVEFA 2005	AMARE 2005	DESSO 2005
Planting date[b]	No./m^2						
Early	0	0	0	0	0	0	0
Mid	191 b[c]	2	189 b	129 b	219 a	0	3,566
Delayed	5,060 a	274	4,763 a	11,505 a	698 a	7,927	–[d]
Preplant weed management							
Tillage	1,227 b	205	1,027 b	3,478 b	257 a	4,013 b	0
Zero tillage + glyphosate	2,338 ab	120	2,218 a	834 b	55 b	11,841 a	0
Zero tillage	4,312 a	89	4,183 a	13,140 a	605 a	0	3,566

[a] Abbreviations: EPHGL, ribseed sandmat; SETVI, green foxtail; AVEFA, wild oat; AMARE, redroot pigweed; DESSO, flixweed.

[b] Early planting date, April 20, 2004 and 2005; mid planting date, June 1, 2004, May 23, 2005; delayed planting date, June 15, 2004 and 2005.

[c] Means within column and parameter followed by the same letter are not significantly different based on Fisher's Protected LSD test (0.05).

[d] Seed production not determined due to abscission prior to harvest.

preplant weed management treatments, despite ZT producing two times more seed than did TILL or ZTPRE. Twenty weed species were identified with barley during the course of this study, and several important species present at harvest did not produce seed regardless of planting date, including kochia, Russian thistle, and horseweed, presumably due to the earliness of barley forage harvest.

Early planting of zero-tillage barley without PRE glyphosate or in-crop herbicide applications resulted in excellent forage yields similar to those produced with TILL and ZTPRE, demonstrating that with this system PRE glyphosate is unnecessary. Likewise, early planting with ZT resulted in WU and WUE of barley similar to that produced in TILL and ZTPRE. Planting date exerted a large influence on weed seed production, with early planting resulting in no weed seed production regardless of preplant weed management system. Conversely, delayed planting resulted in poor forage yield of barley, decreased WUE, and particularly for ZT, the production of numerous weed seeds. By precluding preplant and in-crop herbicide applications, early planting ZT herbicide-free forage barley would decrease selection pressure for herbicide resistance. Annual forage barley is well adapted to the northern Great Plains, and may be a good component of multitactic approaches for improved water and weed management.

Sources of Materials

[1] CNH Canada, Ltd., P.O. Box 5060 Stn. Main, Regina, SK, S4P 3T6 (http://www.flexicoil.com/barton.asp).

[2] Model HMC-67, Hoffman Manufacturing, Inc., Albany, OR 97321 (http://www.hoffmanmfg.com/).

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